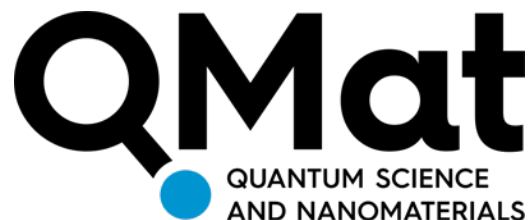


Search for $B \rightarrow K^{(*)} \nu \bar{\nu}$ decays In the Belle II experiment

Masters internship (Unistra, QMat)

03/03/2020 – 28/07/2020

Tutors : Isabelle Ripp-Baudot, Giulio Dujany



Université

de Strasbourg

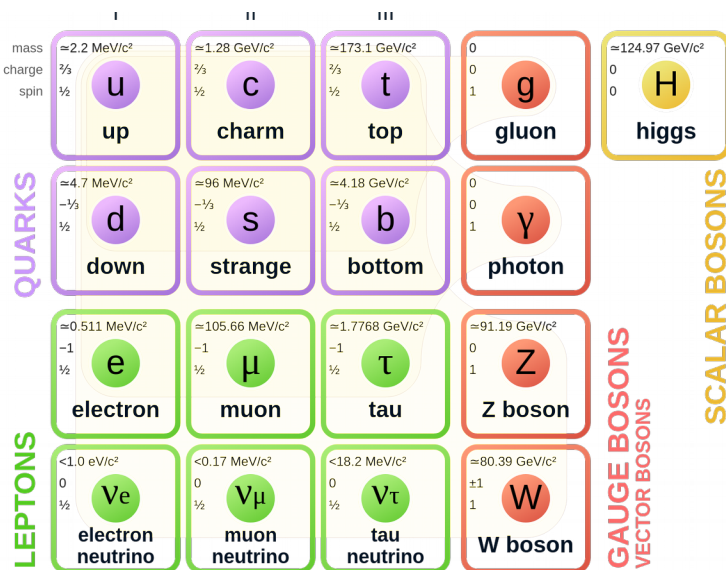


Search for $B \rightarrow K^{(*)} \nu \bar{\nu}$ decays In the Belle II experiment

1. State of the art
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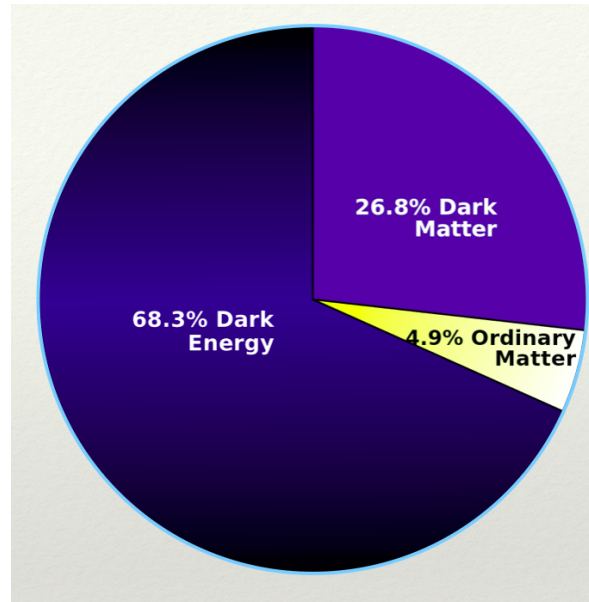
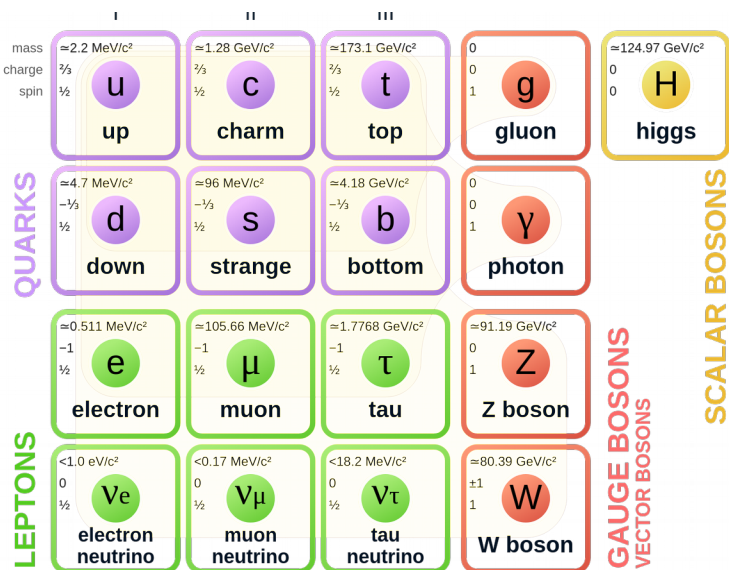
The Standard Model and beyond

Standard Model



The Standard Model and beyond

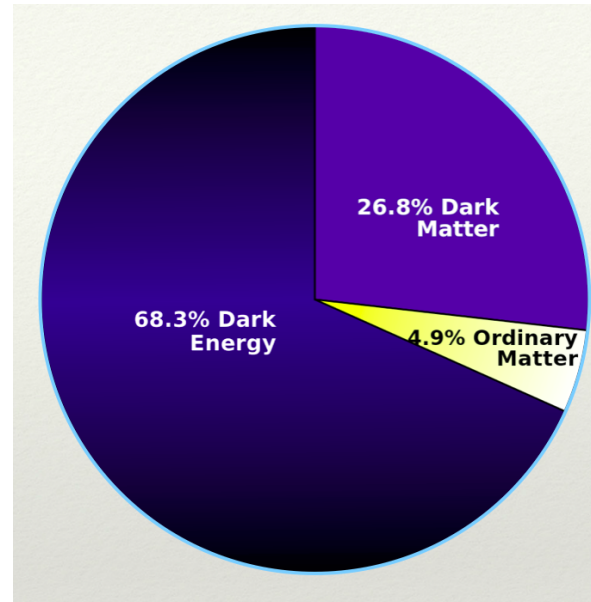
Standard Model $\longrightarrow$ Disagreements



The Standard Model and beyond

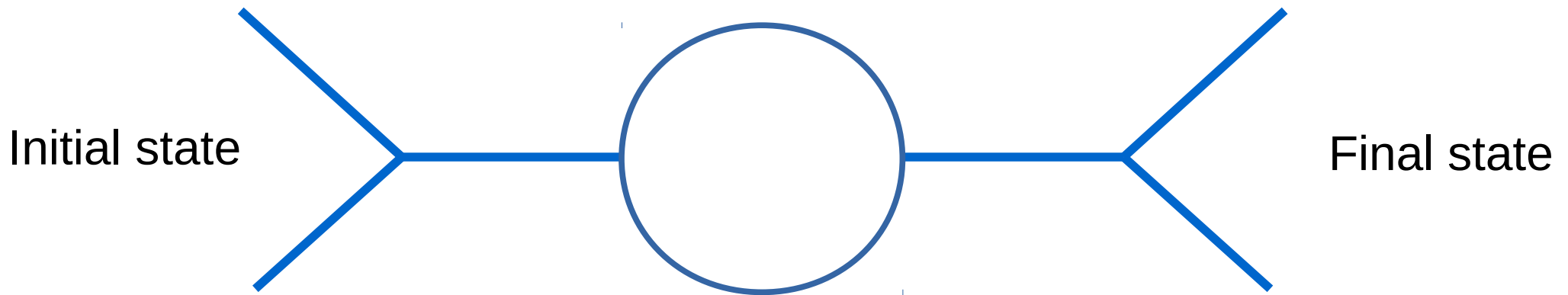
Standard Model → Disagreements → New Physics

	I	II	III		
mass	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	0	$\approx 124.97 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
	u up	c charm	t top	g gluon	H higgs
QUARKS					
	$\approx 4.7 \text{ MeV}/c^2$	$\approx 96 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	d down	s strange	b bottom	γ photon	
					SCALAR BOSONS
	$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.66 \text{ MeV}/c^2$	$\approx 1.7768 \text{ GeV}/c^2$	$\approx 91.19 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	e electron	μ muon	τ tau	Z Z boson	
LEPTONS					
	$< 1.0 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 18.2 \text{ MeV}/c^2$	$\approx 80.39 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
					GAUGE BOSONS VECTOR BOSONS



Search for New Physics

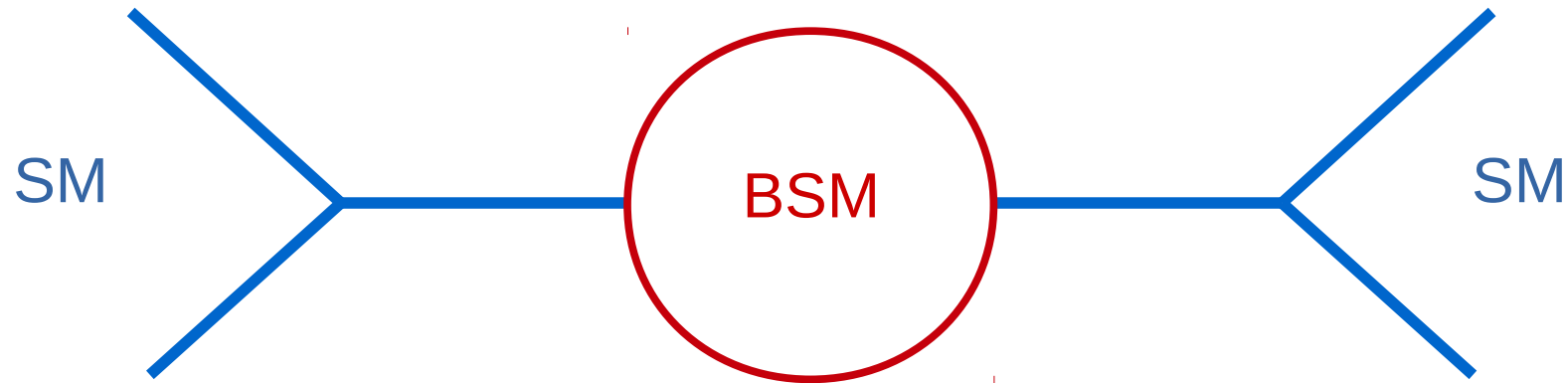
Quantic way



Standard Model probability

Search for New Physics

Quantic way



Skewed probability

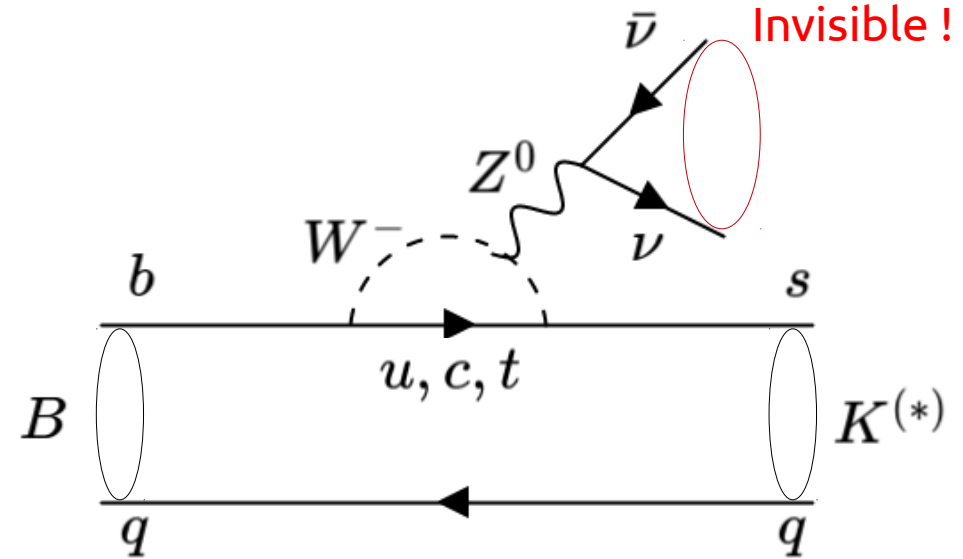


Needs **high precision** : **Belle II experiment**

New Physics in $B \rightarrow K^{(*)} \nu \bar{\nu}$

$B \rightarrow K^{(*)} \nu \bar{\nu}$ decay :

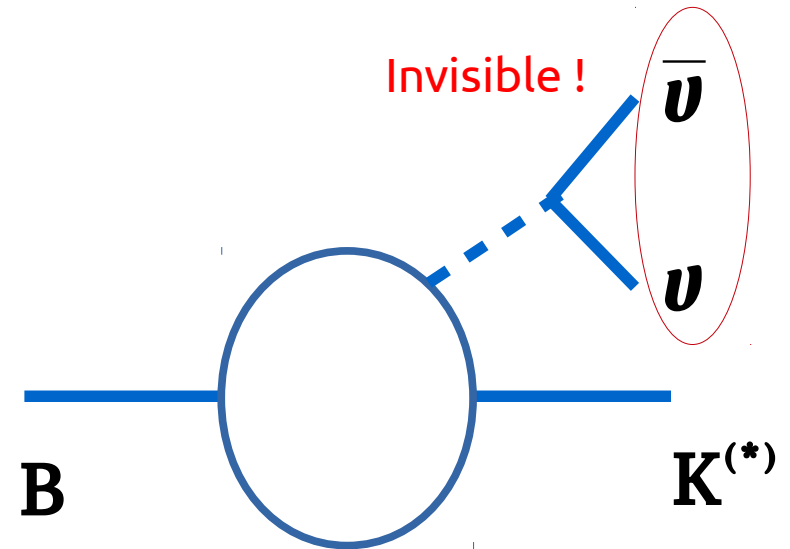
- ▶ Never discovered
- ▶ Partially invisible final state
- ▶ Probability : $\mathcal{B}(B \rightarrow K^{(*)} \nu \bar{\nu}) \sim 10^{-6}$



New Physics in $B \rightarrow K^{(*)} \nu \bar{\nu}$

$B \rightarrow K^{(*)} \nu \bar{\nu}$ decay :

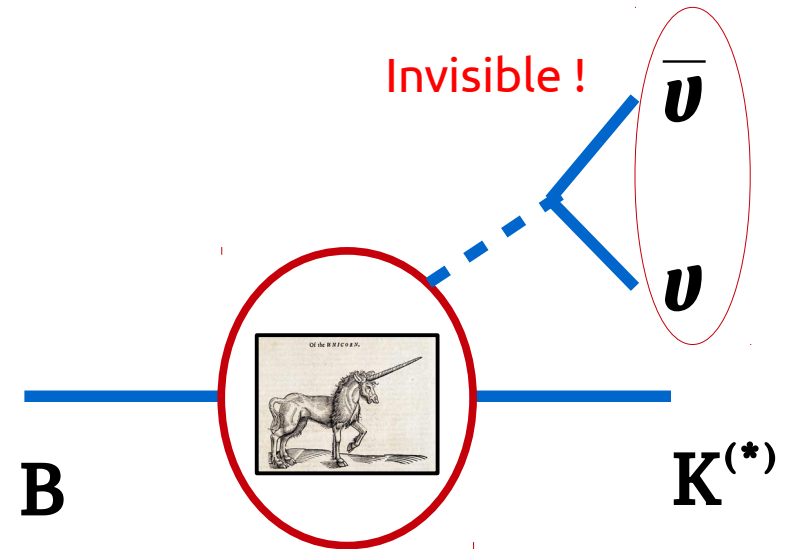
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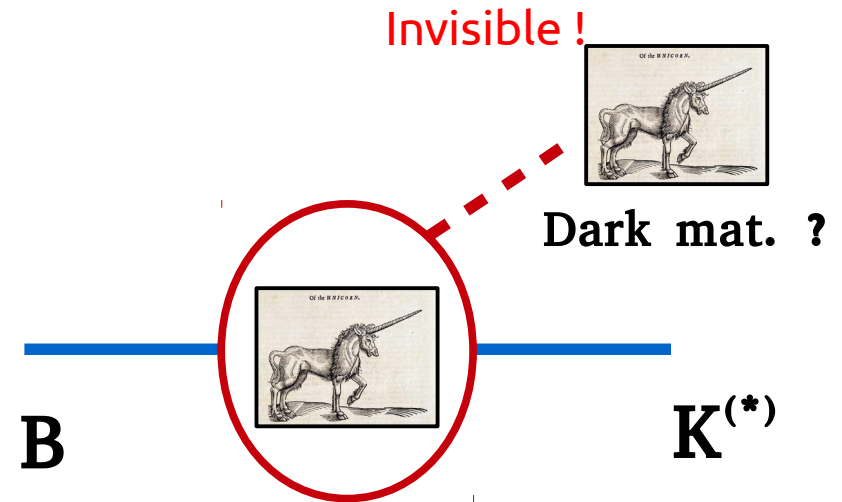
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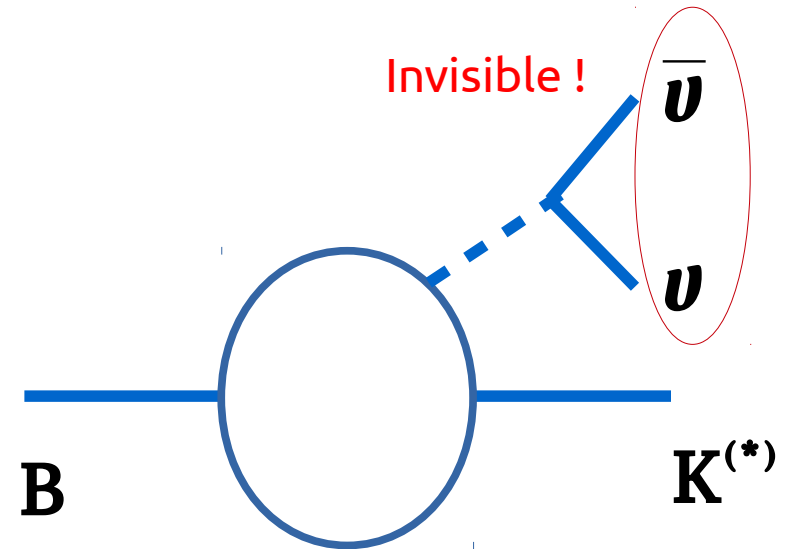
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- ▶ Probability : $\mathcal{B}(B \rightarrow K^{(*)} \nu \bar{\nu}) \sim 10^{-6}$



New Physics in $B \rightarrow K^{(*)}\nu\bar{\nu}$

$B \rightarrow K^{(*)}\nu\bar{\nu}$ decay :

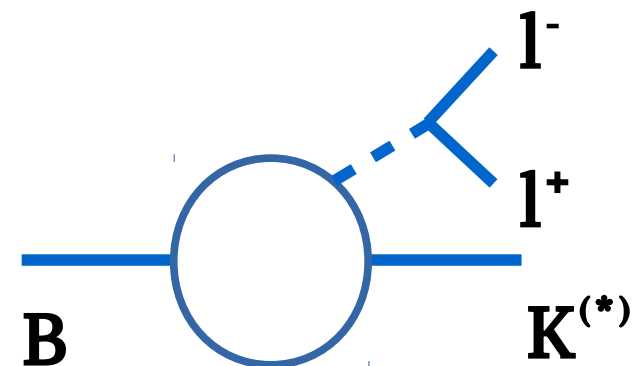
- ▶ Never discovered
- ▶ Partially invisible final state
- ▶ Probability : $\mathcal{B}(B \rightarrow K^{(*)}\nu\bar{\nu}) \sim 10^{-6}$



Similar to $B \rightarrow K^{(*)}l^+l^-$:

- ▶ Discrepancies already observed
[F.Archilli et al. Nature, 2017]

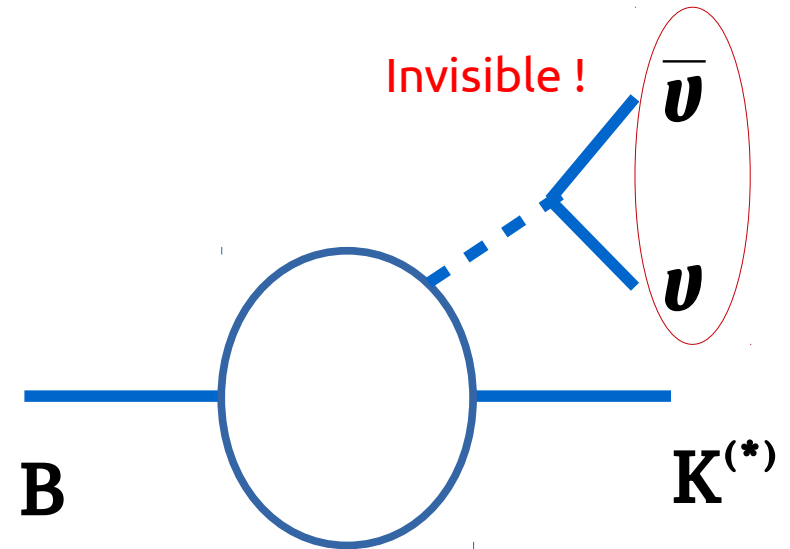
→ inconclusive



New Physics in $B \rightarrow K^{(*)} \nu \bar{\nu}$

$B \rightarrow K^{(*)} \nu \bar{\nu}$ decay :

- ▶ Never discovered
- ▶ Partially invisible final state
- ▶ Probability : $\mathcal{B}(B \rightarrow K^{(*)} \nu \bar{\nu}) \sim 10^{-6}$



Only in **Belle II** !

Search for $B \rightarrow K^{(*)} \nu \bar{\nu}$ decays In the Belle II experiment

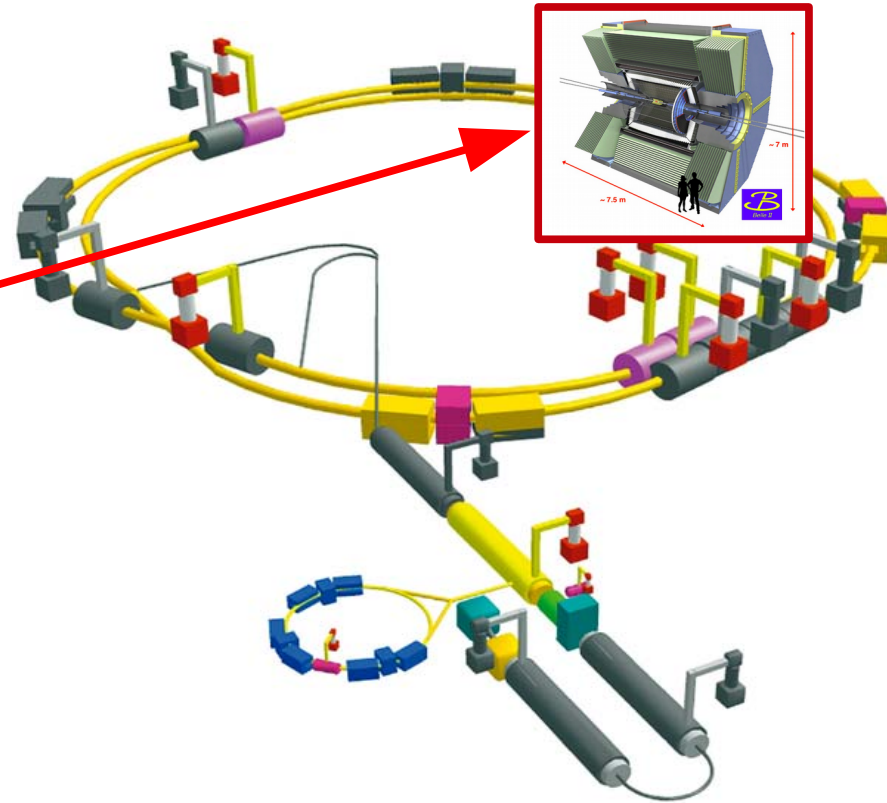
1. State of the art
- 2. The Belle II experiment**
3. Analysis
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The Belle II experiment

- ♦ International collaboration – 2019
 - ♦ e^+e^- collider 7 GeV vs 4 GeV
 - ♦ Instantaneous **Luminosity** highest in the world
($8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$)
- Statistics = **Precision**

The Belle II detector :

- ♦ Improvements since Belle detector (1998 -2010)



The Belle II experiment

EM Calorimeter: CsI(Tl)
waveform sampling

K_L and muon detector
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC
(endcaps)

Vertex Detector
2 layers DEPFET +
4 layers DSSD
(phase 3)

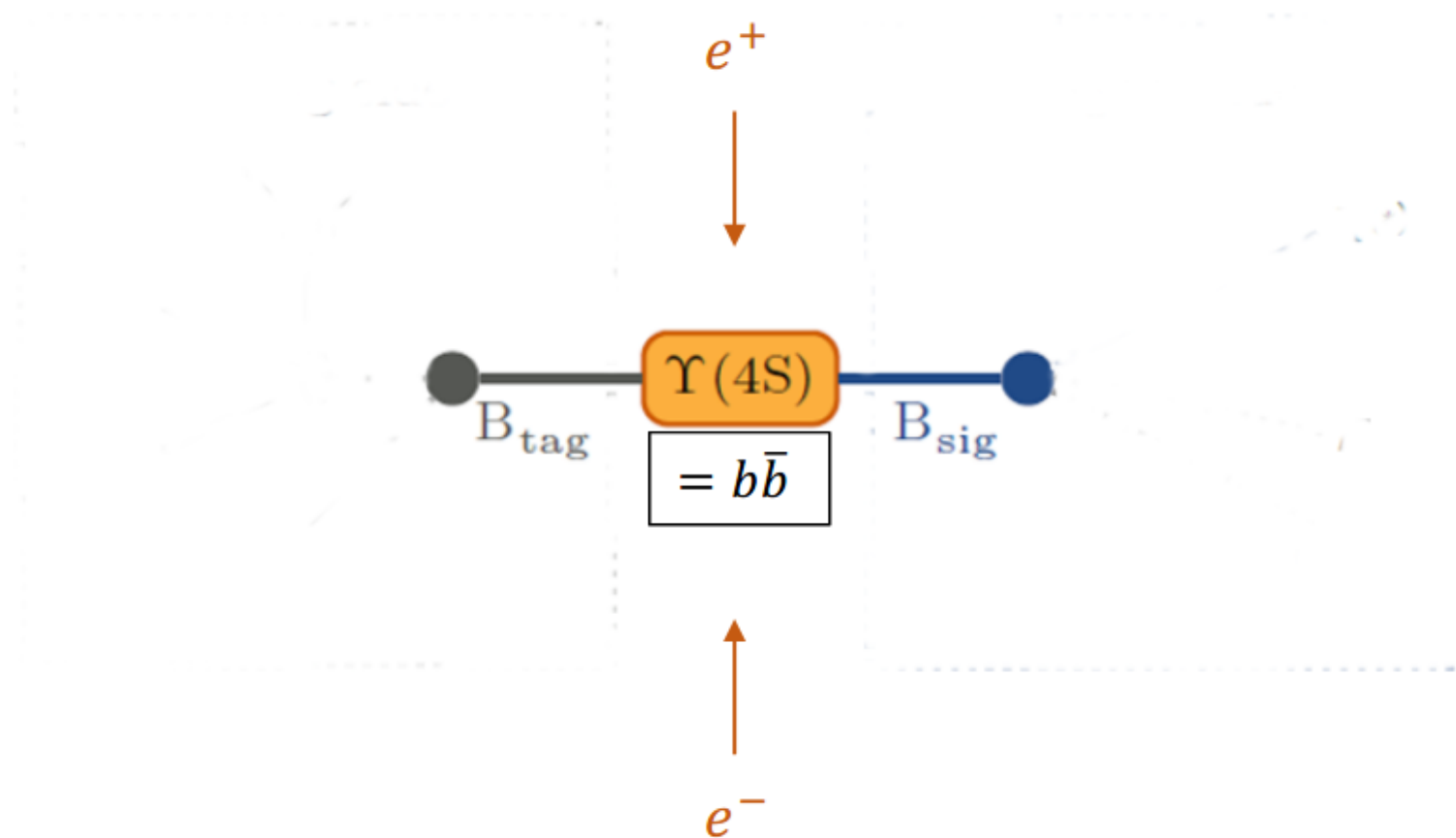
Particle Identification
Time-Of-Propagation
counter (barrel)
Prox. focusing Aerogel RICH

Central Drift Chamber
He (50%):C₂H₆ (50%)
small cells, long level arm,
fast electronics

Collisions in Belle II

$e^+ e^-$ collisions

→ Production of a B meson **pair**

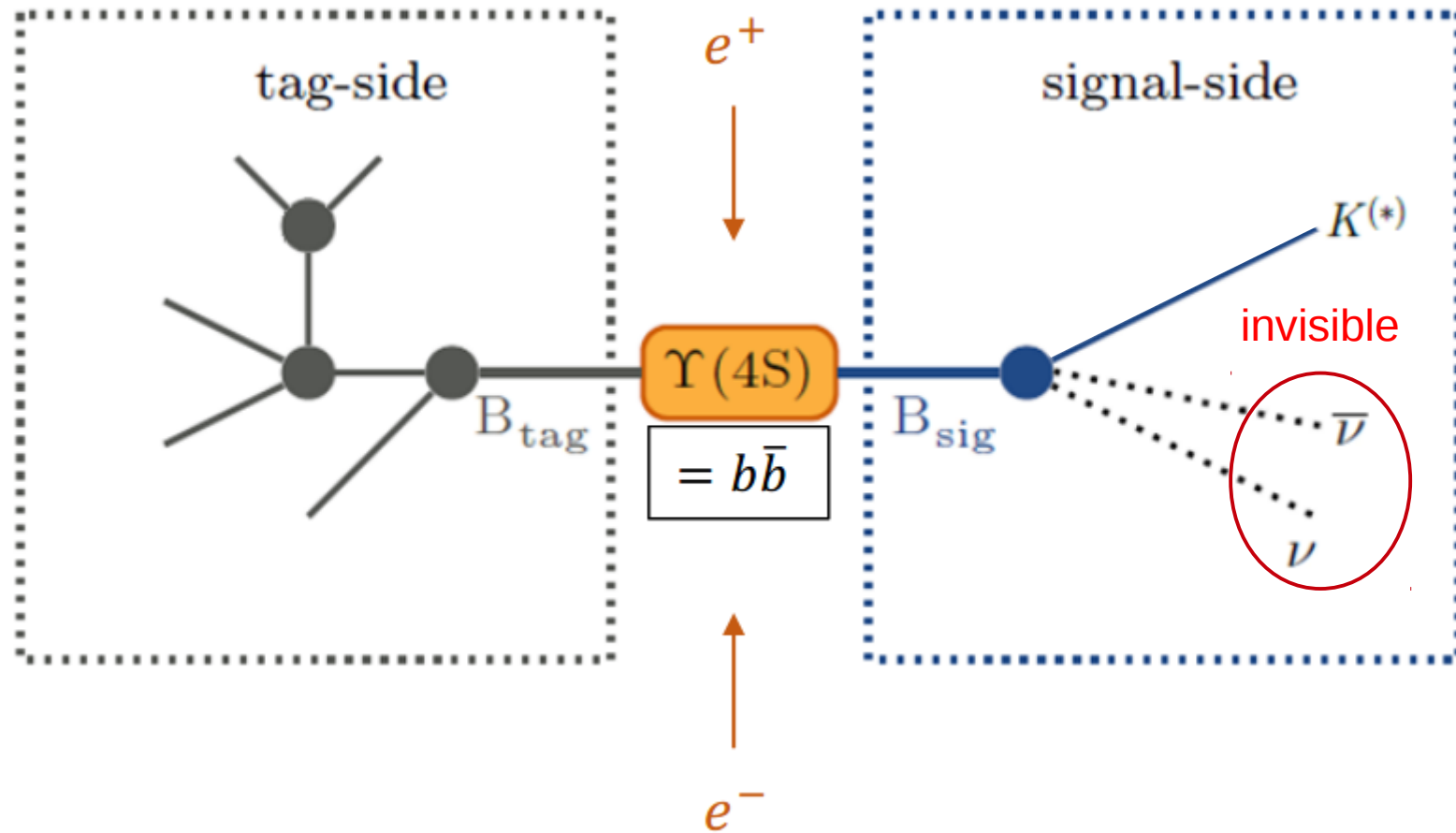


Collisions in Belle II

$e^+ e^-$ collisions

→ Production of a B meson **pair**

→ Mesons decay (only one in our channel)

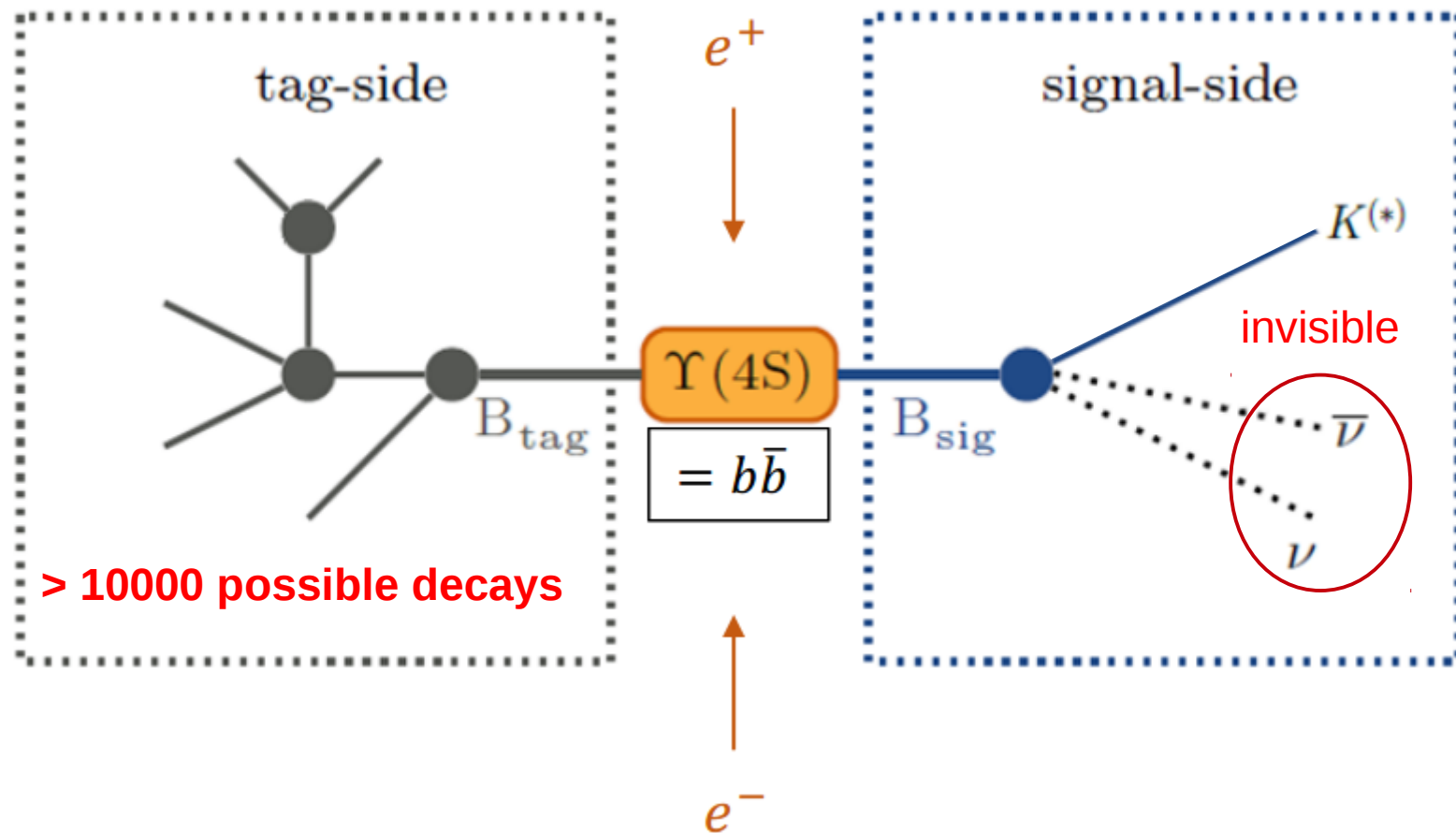


Collisions in Belle II

$e^+ e^-$ collisions

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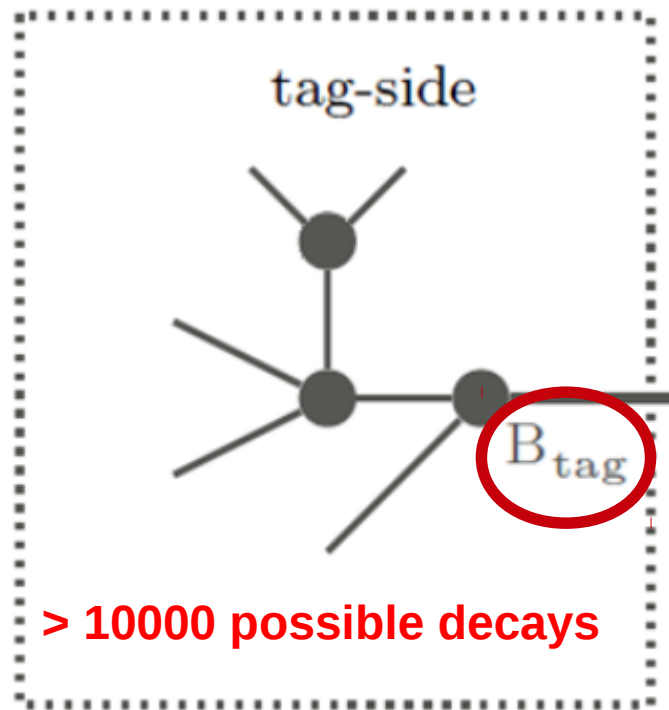


Collisions in Belle II

$e^+ e^-$ collisions

→ Production of a B meson **pair**

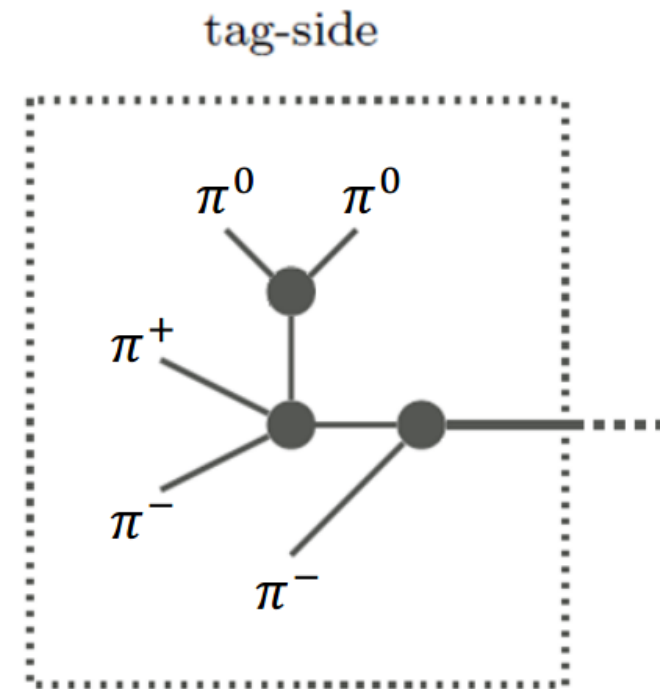
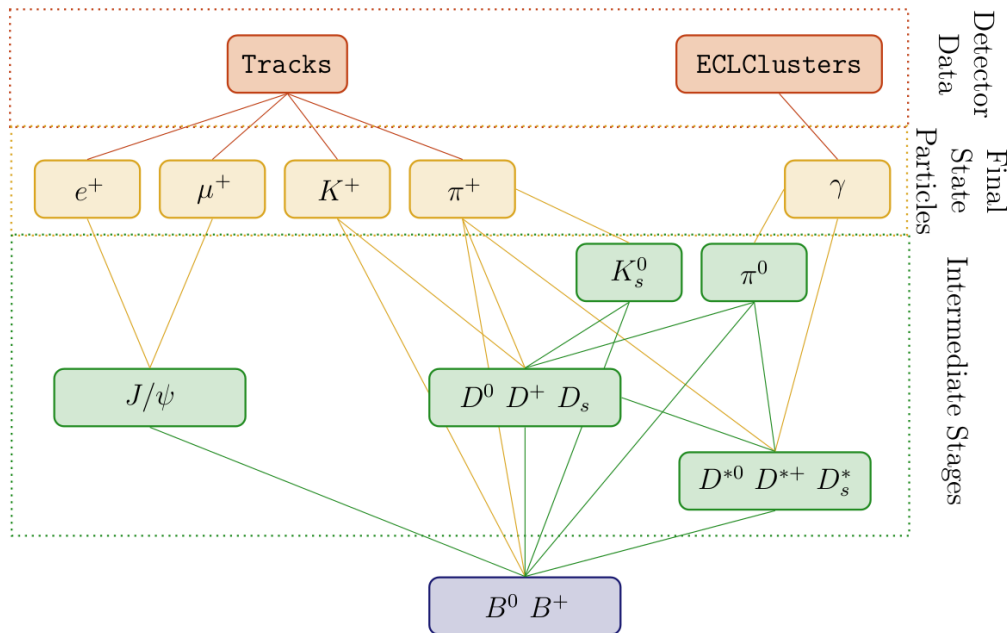
→ Mesons decay (only one in our channel)



Importance of the
Btag reconstruction

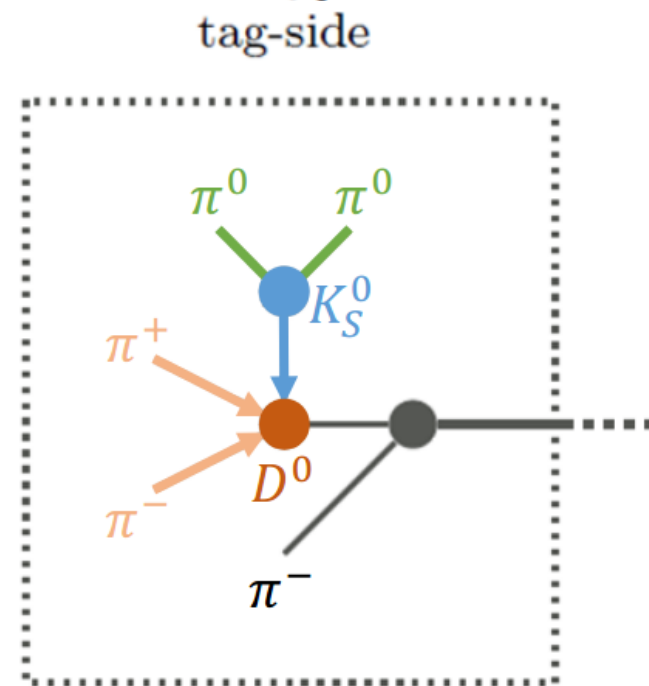
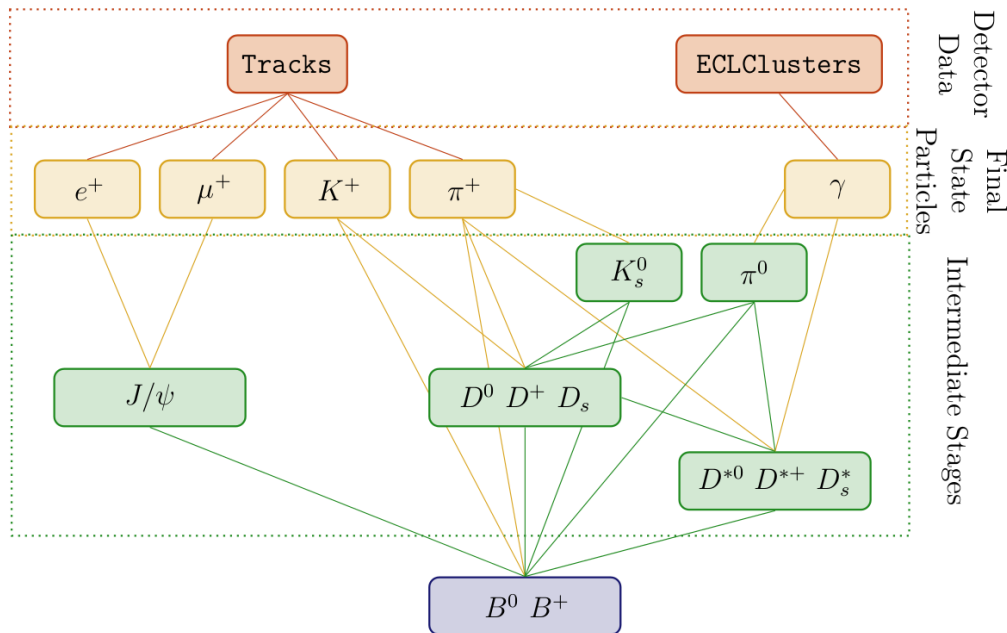
Full Event Interpretation (FEI) algorithm

- How to observe invisible signal ?
 - Btag reconstruction
 - Full Event Interpretation (FEI) : tag side reconstruction algorithm (*machine learning*)
- [T.Keck et al.Computer Software Big Science 2019]



Full Event Interpretation (FEI) algorithm

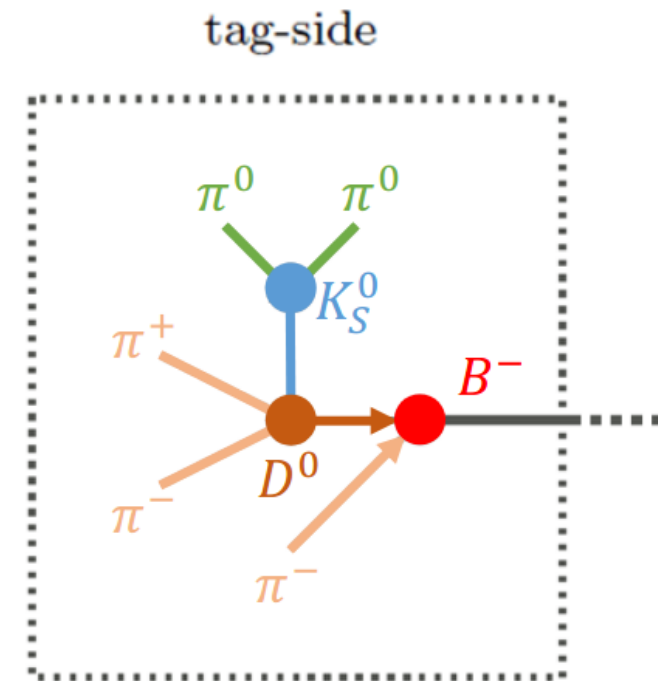
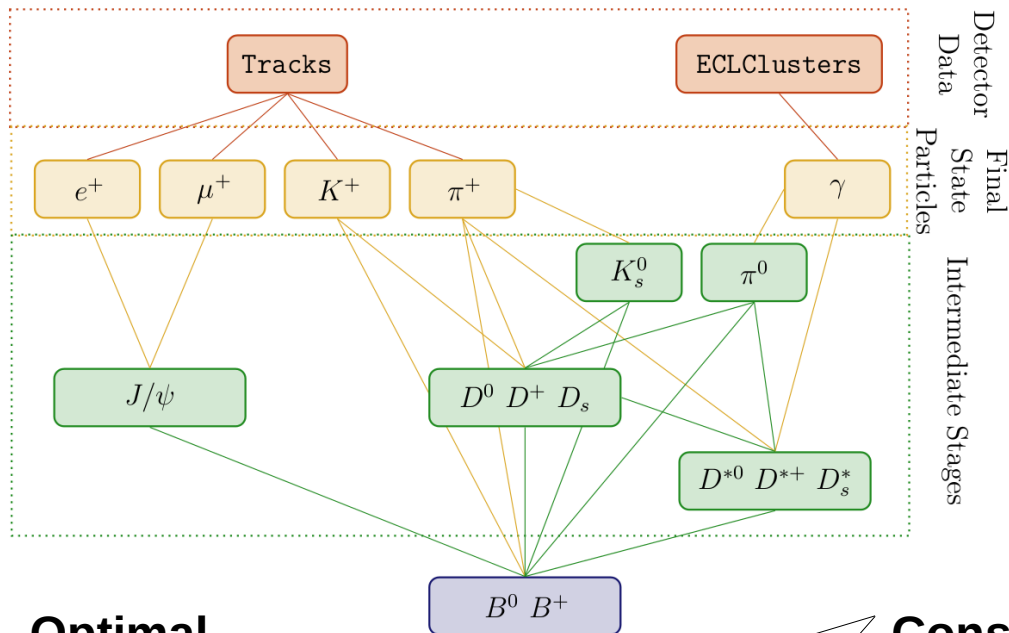
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Full Event Interpretation (FEI) algorithm

- How to observe invisible signal ?
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[T.Keck et al. Computer Software Big Science 2019]



Optimal

Constants

$$N = L \times \sigma \times \epsilon \times \mathcal{B}(B \rightarrow K^{(*)} \nu \bar{\nu})$$

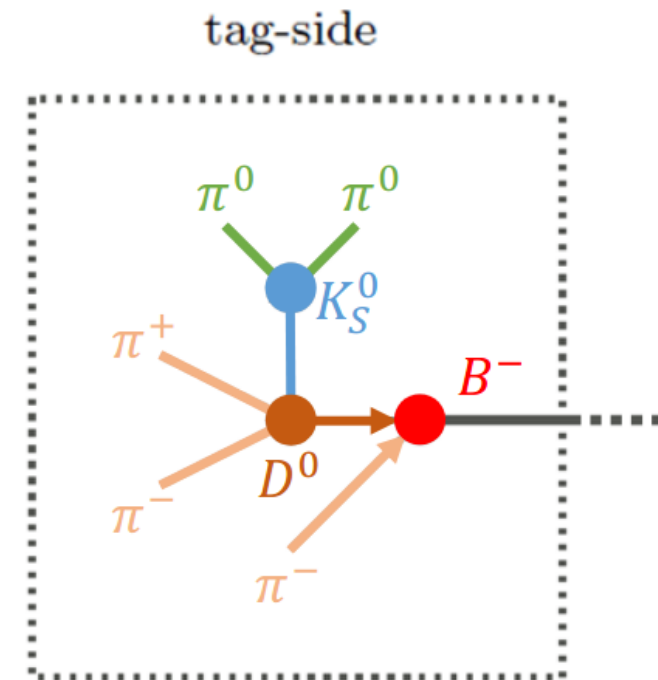
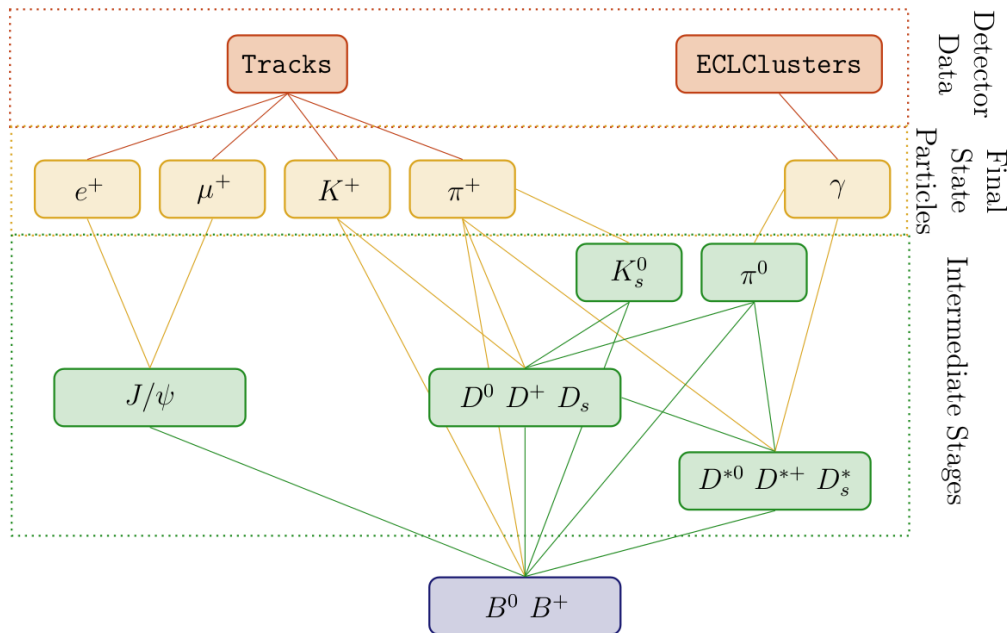
ϵ = efficiency

N = number of signal events

Full Event Interpretation (FEI) algorithm

- How to observe invisible signal ?
 - Btag reconstruction
 - Full Event Interpretation (FEI) : tag side reconstruction algorithm (*machine learning*)

[T.Keck et al. Computer Software Big Science 2019]



$$N = \text{Constant} \times \epsilon$$

N = number of signal events

ϵ = efficiency

Search for $B \rightarrow K^{(*)} \nu \bar{\nu}$ decays In the Belle II experiment

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Internship goal

$$N = L \times \sigma \times \epsilon \times \mathcal{B}(B \rightarrow K^{(*)} \nu \bar{\nu})$$

- ♦ Search for $B \rightarrow K^{(*)} \nu \bar{\nu}$ in Belle until 2010 $\rightarrow$ statistics too low
[O.Lutz et Al. *Physical Review D* 2013]
- ♦ Simulation in Belle II in 2019 in Strasbourg $\rightarrow$ ϵ too low
- ♦ Since 2019 : corrections and enhancements to the simulation

Internship goal

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My work :

Quantify these enhancements and find new ways to improve ϵ

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- ♦ Simulation in Belle II in 2019 in Strasbourg $\rightarrow \epsilon$ too low
- ♦ Since 2019 : corrections and enhancements to the simulation

My work :

Quantify these enhancements and find new ways to improve ϵ

$\epsilon \approx \epsilon_{\text{signal}} \times \epsilon_{\text{tag}} \longrightarrow$ We want to maximize ϵ_{tag}
to optimize the FEI **Learning**

How to measure ε_{tag} ?

Use of $B^0 \rightarrow \nu\bar{\nu}$ as a tool :

Invisible final state $\rightarrow \varepsilon = \varepsilon_{\text{tag}}$

How to measure ϵ_{tag} ?

Use of $B^0 \rightarrow \nu\bar{\nu}$ as a tool :

Invisible final state $\rightarrow \epsilon = \epsilon_{\text{tag}}$

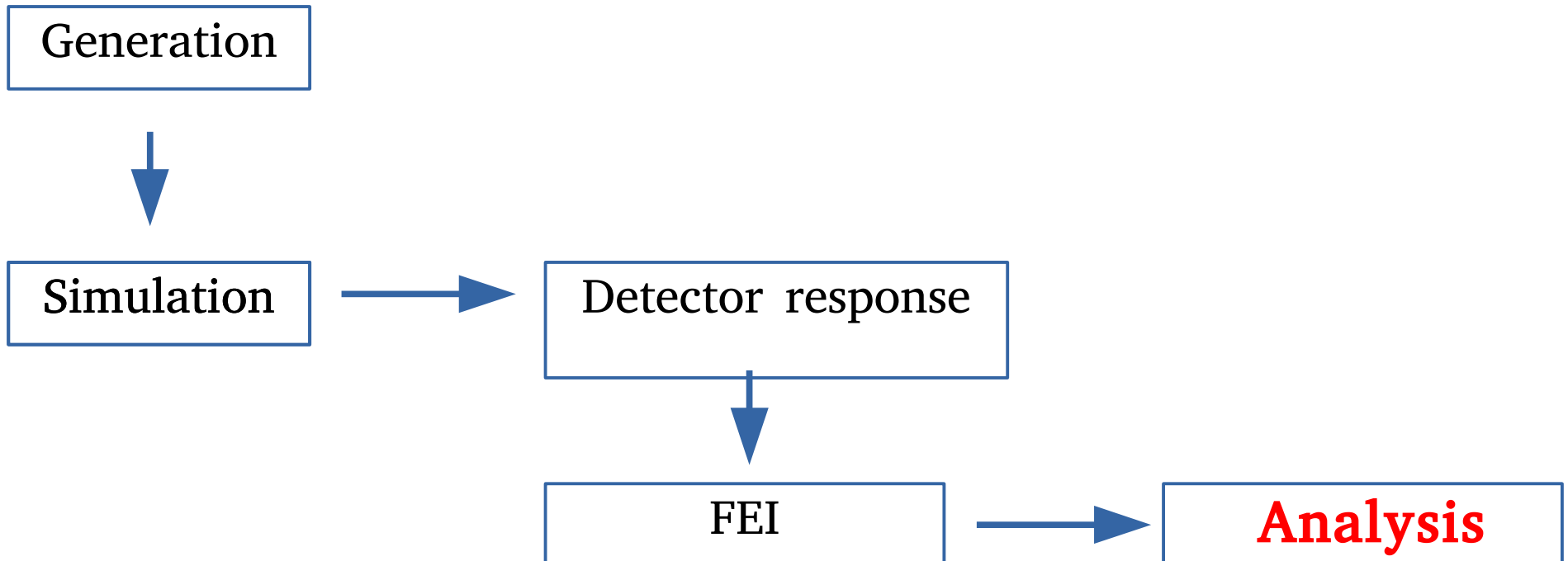
We simulate B meson pairs with one B decaying in $B^0 \rightarrow \nu\bar{\nu}$ (signal) and the other decaying generically (tag)

♦ Study done on Monte Carlo **simulations**

♦ Comparison between 3 simulations :

Belle II $\rightarrow$ 'B2_2020', 'B2_2019'
Belle $\rightarrow$ 'Belle'

Analysis



Search for $B \rightarrow K^{(*)} \nu \bar{\nu}$ decays In the Belle II experiment

1. State of the art
2. The Belle II experiment
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- 4. Results**

Measured performances

	Belle	B2_2019	B2_2020
% of reconstructed Btag decay chains	$4,0 \pm 0,2 \%$	$4,3 \pm 0,3 \%$	$10,0 \pm 0,4 \%$
Efficiency on FEI known chains	$(1,87 \pm 0,01)10^{-2}$	$(0,71 \pm 0,01)10^{-2}$	$(2,43 \pm 0,02)10^{-2}$
ϵ_{tag}	$(0,54 \pm 0,01)10^{-3}$	$(0,52 \pm 0,01)10^{-3}$	$(1,78 \pm 0,01)10^{-3}$

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			X 2,5
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Measured performances

	Belle	B2_2019	B2_2020
% of reconstructed Btag decay chains	☹	☹	☺ X 2,5
Efficiency on FEI known chains	☺	☹	☺ X 3
ϵ_{tag}	☹	☹	☺

Algorithm upgrade

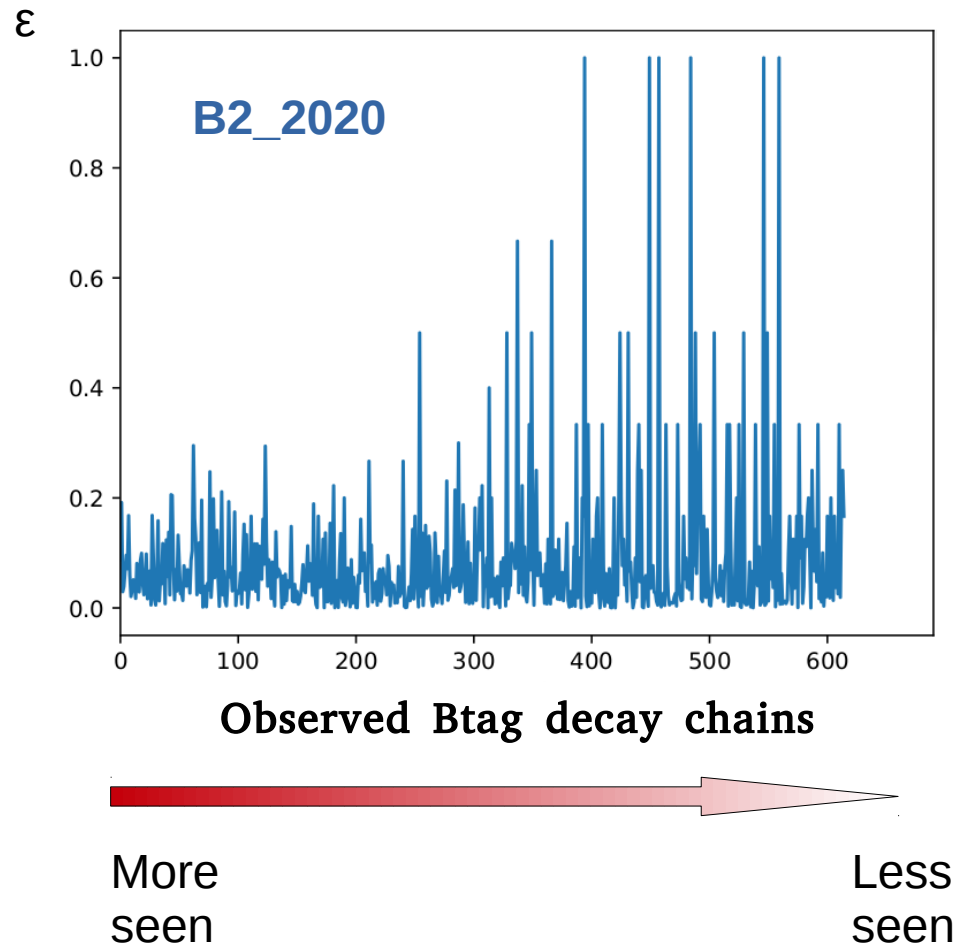
New detector

Measured performances

	Belle	B2_2019	B2_2020
% of reconstructed Btag decay chains	☹	☹	☺ X 2,5
Efficiency on FEI known chains	☺	☹	☺ X 3
ϵ_{tag}	☹	☹	☺

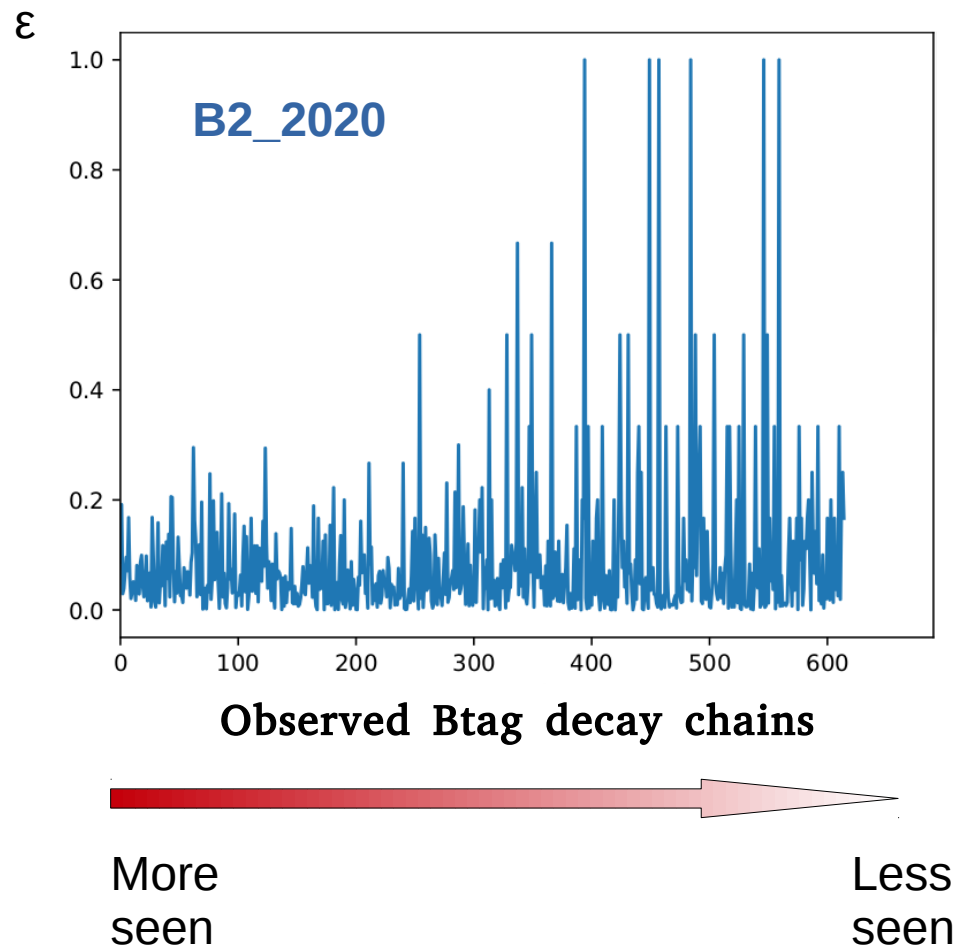
- ◆ High impact from 2019 upgrades
- ◆ Still needs $\epsilon_{\text{tag}} \sim \mathbf{x3}$ to discover $B \rightarrow K^{(*)} \nu \bar{\nu}$ within **3 years**

Efficiency by Btag decay chain



- ◆ Study done for the first time in the collaboration
- ◆ Efficiency different for each chain

Efficiency by Btag decay chain



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- ◆ Efficiency different for each chain

Interesting to understand and optimize the reconstruction

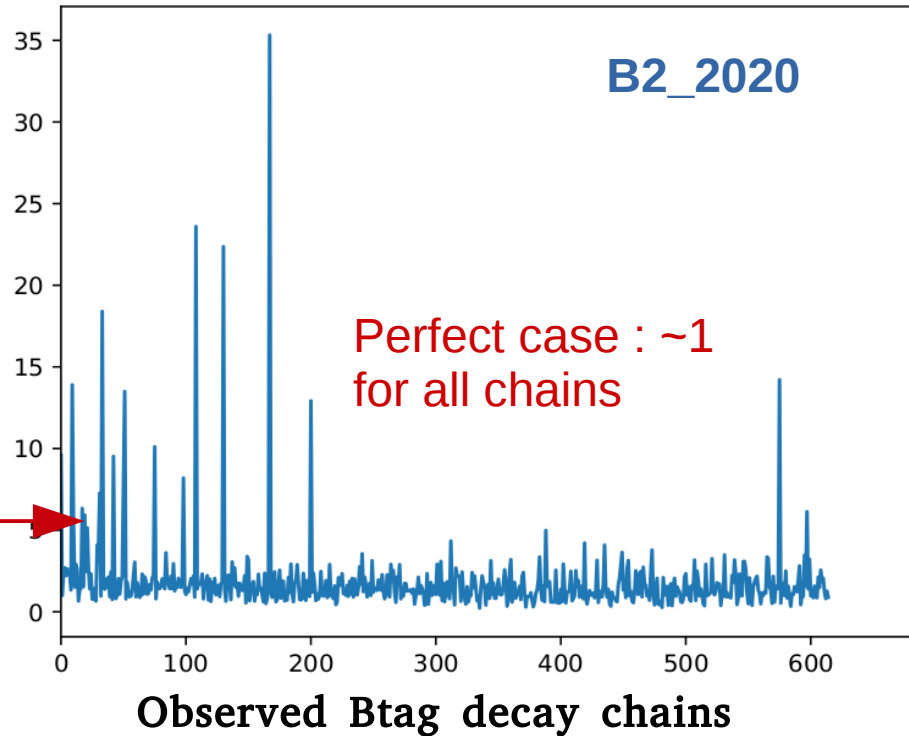
Decay chains simulation discrepancies

Number of times simulated/
Number of times expected

B2_2020

Perfect case : ~1
for all chains

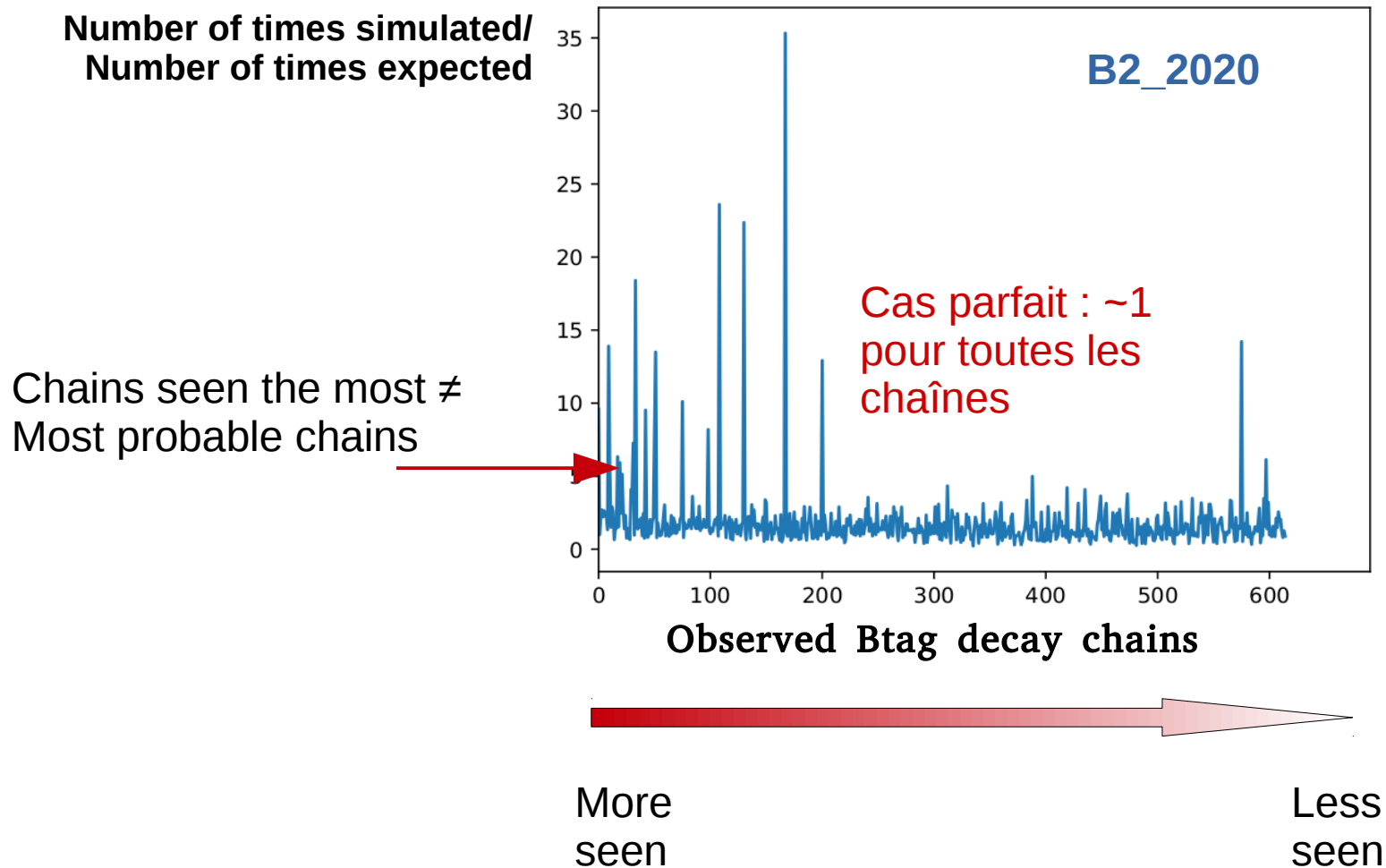
Chains seen the most $\neq$
Most probable chains



More
seen

Less
seen

Decay chains simulation discrepancies



- ◆ Some chains over represented in the simulation
- ◆ Presented to the collaboration → is going to be corrected

Summary

From my results :

- ♦ Assessment of upgrades → **measurement** of $\varepsilon_{\text{for B2_2020}}$
- ♦ Search for ways of optimization → First **study** by chains
- ♦ Upgrade → **discovery** of the simulation bias

To do next :

- ♦ Convolute these results to the signal reconstruction of $B \rightarrow K^{(*)} \nu \bar{\nu}$
- ♦ Implement new ways to improve efficiency

Thank you for your attention !

Bibliography

[1] F. Archilli , M.-O. Bettler , P. Owen & K. A. Petridis,
Flavour-changing neutral currents making and breaking the standard model.
Published in : Nature 546 (2017) 7657,221-226.

[2] T. Keck et al.
The Full Event Interpretation : An Exclusive Tagging Algorithm for the Belle II Experiment.
Published in : Computer Software Big Science 3 (2019) 1, 6.

[3] O. Lutz et al.,
Search for $B \rightarrow h (*) \nu \bar{\nu}$ with the full Belle $\Upsilon(4S)$ data sample.
Published in : Physical Review D 87 (2013) 11, 111103.